# Wave-Sediment Interaction in Muddy Environments: A Field Experiment


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## LONG-TERM GOALS

The long-term goal of the proposed work is to study and describe quantitatively the interaction between wave, currents and seabed sediments in shallow water over a bed characterized by heterogeneous, mud-dominated sediments.

This report includes two projects:

1. “Wave-Sediment Interaction in Muddy Environments: A Field Experiment”, funded by Coastal Geosciences, The Coastal Geosciences project includes a field experiment on the Atchafalaya shelf, Louisiana, in Years 1 and 2 (2007-2008) and a data analysis and modeling effort in Year 3 (2009).

2. “A System for Monitoring Wave-Sediment Interaction in Muddy Environments”, funded by The DURIP program.

## OBJECTIVES

The immediate objective of Year 1 (2007) of the Coastal Geosciences (CGS) project was to conduct a pilot field experiment to test instrumentation and data analysis procedures for the major field experiment effort scheduled in Year 2 (2008). The project deployed two tripods carrying instrumentation for coherent measurements of waves and near-bottom sedimentary processes, including vertical structure of velocities and suspended sediment concentration, and position and motion of the lutoclines. The project represents an effort to obtain basic information (previously lacking) about the processes associated fluid-mud layers formation, necessary for effective modeling of wave propagation over muddy shelves. The goal of the DURIP project was to build up the field instrumentation base to support the CGS-funded field experiment effort.

# Report Documentation Page

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## APPROACH

Theoretical formulations of bed-induced wave dissipation are based on the assumption that wave motion reaches the bottom and interacts directly with bed sediments. Physical mechanisms for wave dissipation over muddy seabeds that have been proposed, are based on different models of sediment rheology: poro-elastic solids (Yamamoto et al., 1978; Yamamoto and Takahashi, 1985), viscous Newtonian fluids (Dalrymple and Liu, 1978), Bingham fluids (Mei and Liu, 1987), generalized Voigt solids (Jiang and Mehta, 1995; Jiang and Mehta, 1996), and non-Newtonian fluids (Chou et al., 1993; Foda et al., 1993). With the exception of liquefaction processes, these models assume a single, well-defined mud phase.

However, theoretical and laboratory evidence suggests that mud and wave processes evolve on comparable time and spatial scales, and are strongly coupled. On one hand, the efficiency and characteristics of mud-induced wave damping depends strongly on mud state. Smooth and hard consolidated muds dissipate waves at a similar, or even weaker, rate than sandy bottoms (Yamamoto and Takahashi, 1985; Lee, 1995, and others). Over non-Newtonian fluid muds (concentrations >5 $kg/m^3$), wave dissipation is significantly stronger (Gade, 1957; Chou et al., 1993; Foda et al., 1993). On the other hand, even under mildly energetic waves mud state can change from consolidated to fluid over the duration of one storm (Chou et al., 1993; Foda et al., 1993; also deWitt, 1995). The similar scales of evolution and the strong coupling suggest that the applicability of the above models is rather limited. While it has been hypothesized that wave-sediment coupling should be active in the field (Allison et al. 2000; Sheremet and Stone, 2003; Sheremet et al., 2005, and others), it has not been observed directly.

The basic hypothesis of the proposed work (supported by our ongoing field experiments on the Atchafalaya shelf) is that wave damping by fluid mud is only one of several dissipation mechanisms that could be active on a muddy shelf. The Louisiana coast exhibits a gradation of sediment age, type and grain size, from soft muds in the west, to more consolidated mud and fine sands to the east. The planned Dalrymple-team MURI field experiment site covers only a small fraction of this diversity, both conceptually and geographically. We propose to enhance the planned MURI field experiment by:

1. increasing the resolution of the Dalrymple-team observation array in intermediate and shallow water,

2. expanding its physics and geographic coverage to the east (Atchafalaya and Terrebonne shelf) to examine wave dissipation in areas with different sedimentary and morphologic characteristics.

## RESULTS

The planned MURI instrument array specifies three instrument clusters to be deployed in 2008 on the western Louisiana shelf at the 15-m, 10-m and 5-m isobaths. Since soft muds are primarily confined within the 5-m isobath near the MURI site, we proposed to deploy instrumentation on a fourth instrument cluster to monitor wave, current and sediment dynamics at an additional location in shallower water landward of the MURI sites (2-m isobath) and east of the main transect (Figure 1). It has been suggested (Sheremet & Stone, J. Geophys. Res. 2003) that, due to the very mild bathymetry of the Louisiana shelf, useful comparisons can be made between measurements collected at locations as far apart as Atchafalaya and Terrebonne bays. Figure 1 details the deployments carried out in Year

1 (2007) and the planned deployments for the Year 2 experiment. The primary objective is to deploy two (2007) or three (2008) additional clusters to the east of the MURI location to monitor hydrodynamics and sediment at a mud site which is expected to behave differently than sites dominated by soft/fluid mud beds. To monitor shoreward wave evolution, the instrument clusters will be distributed in a cross-shore configuration, parallel with the pair deployed at the MURI experiment site. Another, simpler cluster will be deployed on Terrebonne shelf in 2008 to provide reference data from a sandy environment. The instruments will be deployed for two-week periods, with short instrument turnaround for offloading data, cleaning sensors and replacing batteries. A fourth instrument cluster will be deployed in 2008 at the MURI site in shallow water (2 m; Fig. 1) to supplement the other instrumentation. The additional instrumentation (two more instrument clusters) planned for 2008 deployment have been purchased with the DURIP funds.

The large instrument clusters are capable of high resolution measurements of full water column hydrodynamics and near-bed sediment dynamics. Directional wave and current dynamics are monitored throughout the water column using an upward looking ADCP (at about 0.5-m vertical resolution), a downward looking PC-ADP which monitor near-bed flow (approximately 2-cm vertical resolution). A PUV gauge (co-located ADV and pressure sensor) are used for high resolution wave measurements. During our previous experiments we have developed a procedure to keep PC-ADP and the PUV recording continuously at 2 Hz for durations of up to two weeks. Sediment dynamics (suspended and in-bed) are monitored with ABS (sediment layer dynamics), OBS (suspended sediment), accelerometers and pore pressure sensors (in-bed sediment motion). The smaller, reference instrument pod are outfitted with an upward looking ADCP and a PUV (ADV + Pressure) gauge.

Figure 2 shows observations of current (PC-ADP), wave (ADCP) and sediment evolution at the 2007-2008 Atchafalaya shelf instrument cluster locations (Figure 1a, red circles) near the 5-m isobath at a distance of approximately 4 km from each other. The storm is associated with intense (about 1.5 m height) swells (Figure 2a). The position of the bottom is identified from the PC-ADP signal using two independent methods: the zero-velocity level (hydrodynamic bottom, Figure 2b); the strongest reflecting surface, based on the level of maximum intensity of the return signal (Figure 2d). The two estimates agree most of the time, with the exception of two 1-day events (March 10 and March 11). The vertical structure of velocity (Figure 2b-c) shows that these events are near-bed flows independent of the upper water column movement (flow direction is opposite to the upper column flow during the second event). The fact that the upper boundary is also a strong sound reflector suggests that these flows are fluid mud layers.

Several facts are obvious about the evolution of net wave dissipation, shown in Figure 3:

1. wave dissipation increases during the storm;
2. it shows no significant response to the presence of fluid mud layers;
3. it peaks after the storm.

These results suggest that bottom sediment state changes on the storm time scale and affects significantly wave dissipation. Surprisingly, occurrences of near-bottom fluid-mud layers do not seem to dynamically significant for wave propagation, at least at this location on the shelf. The mud state that appears to be most efficient at dissipating wave energy is realized in the wake of the storm, probably as soft, unconsolidated (jell-like) visco-plastic solid.

Our observations to date also indicate that mobile fluid muds associated with cold front passage (such as are shown in Fig. 2-3) are relatively transitory features (present for hours) that are created during strong wave-current stress that may involve liquefaction of the bed (observed through rapid sinking of the tripod feet) and then move downslope and are deposited. A second type of (stationary) fluid mud has also been observed (Fig. 4) that is present for days at a time during relatively low wave-current stress periods with limited motion (from ADCP observations) below the lutocline.

## IMPACT/APPLICATIONS

Much of the present and near-future Navy capability on predicting regional and nearshore processes assumes a sandy (non-cohesive) sedimentary environment. The present research enhances this capability by providing field data essential for model validations and by identifying processes and developing mechanisms which allow expansion into areas with significantly different characteristics.

## RELATED PROJECTS

The project is coordinated in collaboration with other MURI related projects. The closest collaboration is planned with the Elgar/Raubenheimer experiment. Also related are the Trowbridge/Traykovski and Kineke/Bentley, and Herbers/O'Reilly experiments. We have a strong logistical and scientific collaboration with NRL researchers (Holland/Reed/Furokawa) working in the area.

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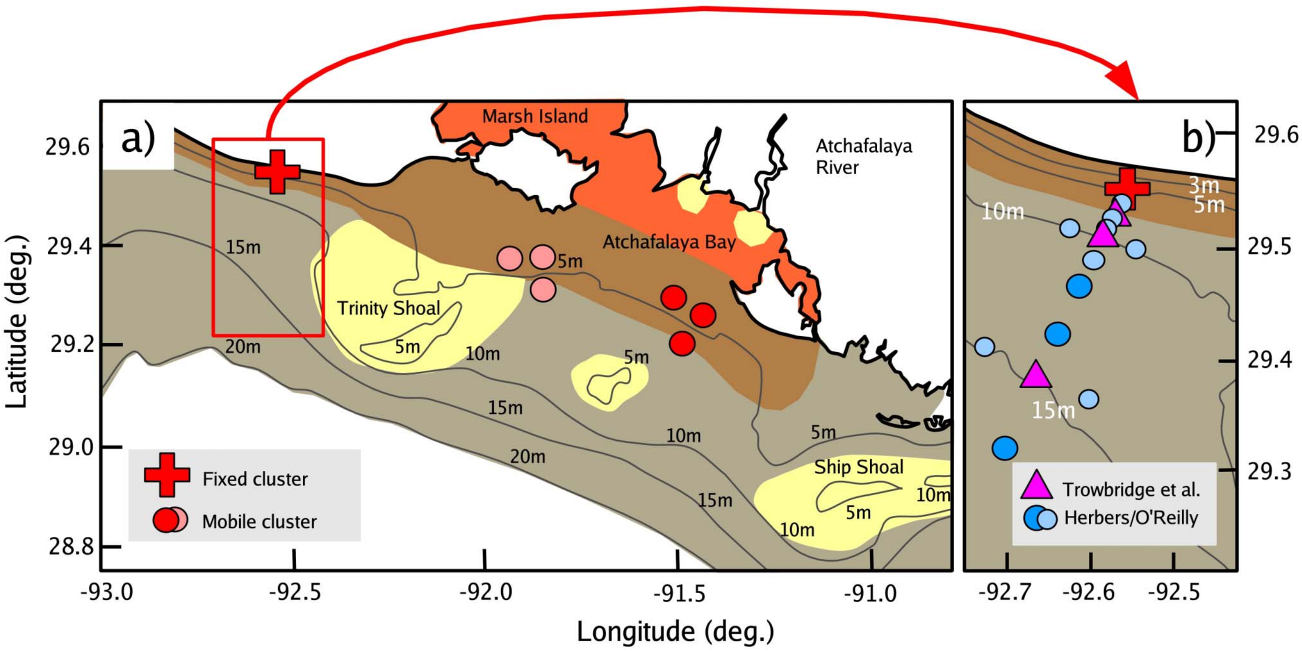


***Figure 1. a) Plan view of the Atchafalaya shelf with the location of 2007 deployment locations and proposed locations for 2008. b) Magnified area of the MURI experiment with the locations of the three MURI platforms (magenta triangles) and Herbers/O'Reilly PUV tripods (light blue circles) and buoys (dark blue circles). Elgar/Raubenheimer array, located between the 6- and 1-m isobaths, is too small to be reproduced here.***

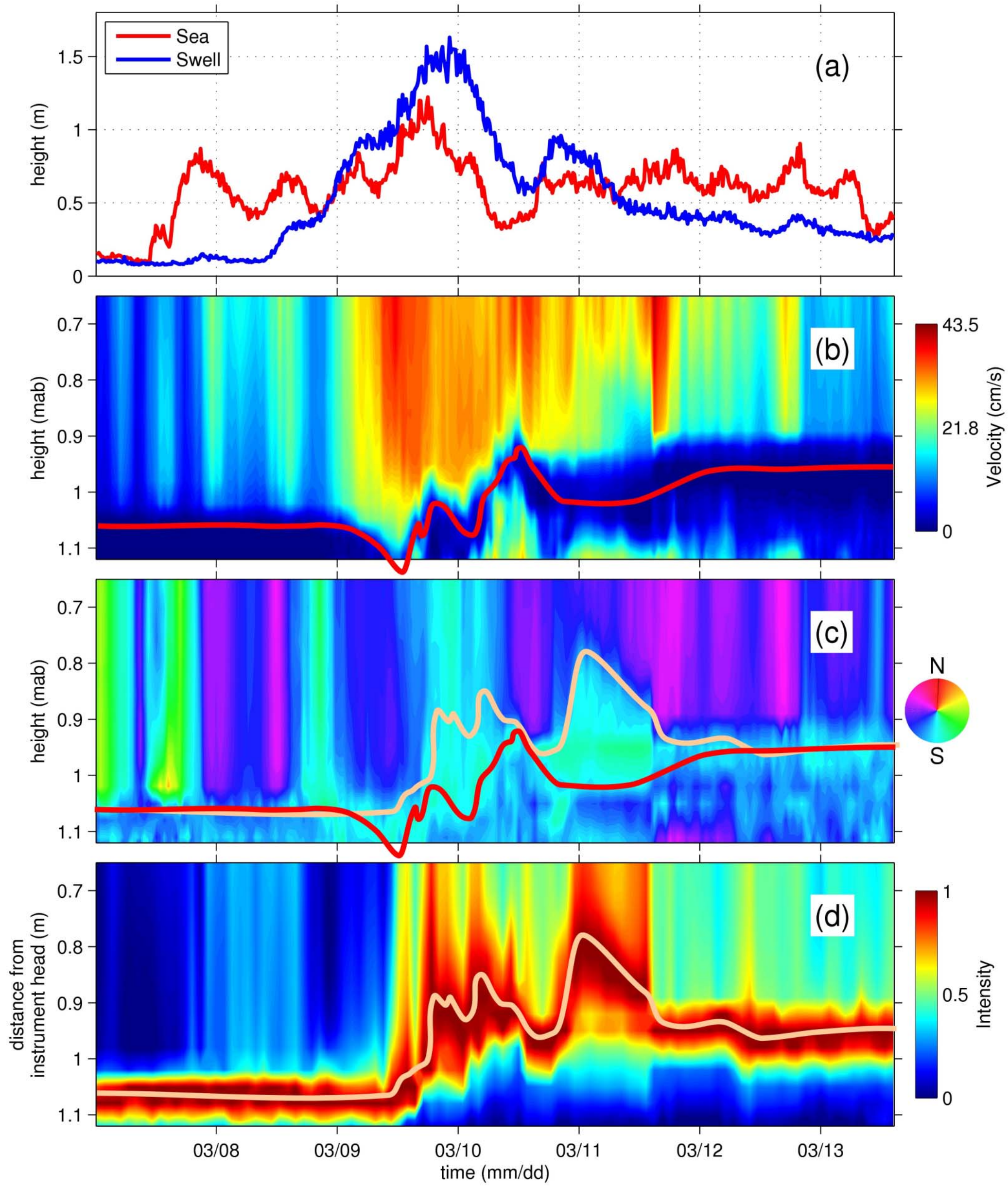


***Figure 2. Observations of the formation of near-bed fluid mud layers during a the passage of a cold front. a) Sea and swell significant height; b) Vertical structure of horizontal current velocity; c) direction of horizontal current velocity; d) echo strength for the vertical PC-ADP beam, versus time. Red curve marks the approximate location of the hydrodynamic bottom (zero velocity); pink curve marks the approximate location of the strongest reflector of the vertical PC-ADP beam.***

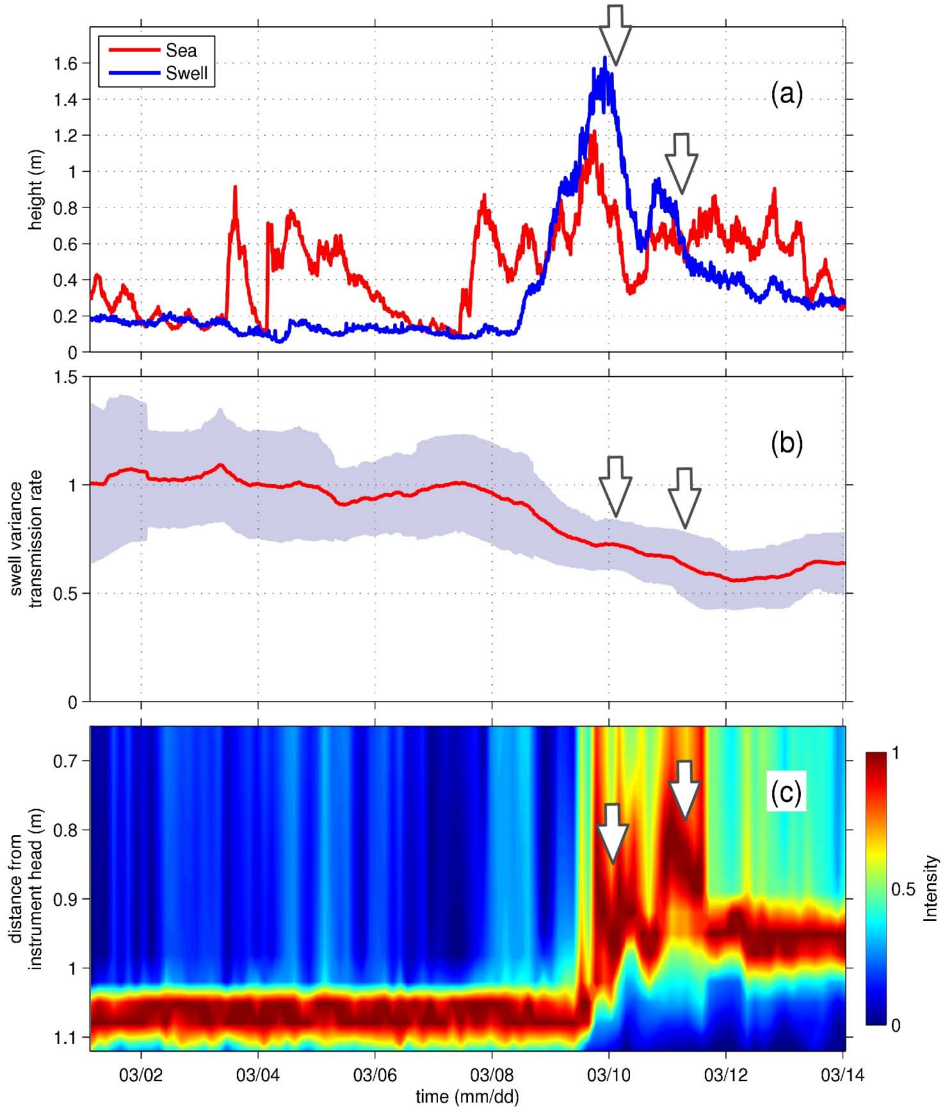


***Figure 3. Wave response to changes in the structure of the muddy sea bed. a) Sea and swell significant height; b) Swell variance transmission rate over a distance of approximately 10 km (red line: moving average value; gray area has width equal to one standard deviation); c) Echo strength for the vertical PC-ADP beam, versus time. Arrows mark the two observed mud layer events.***

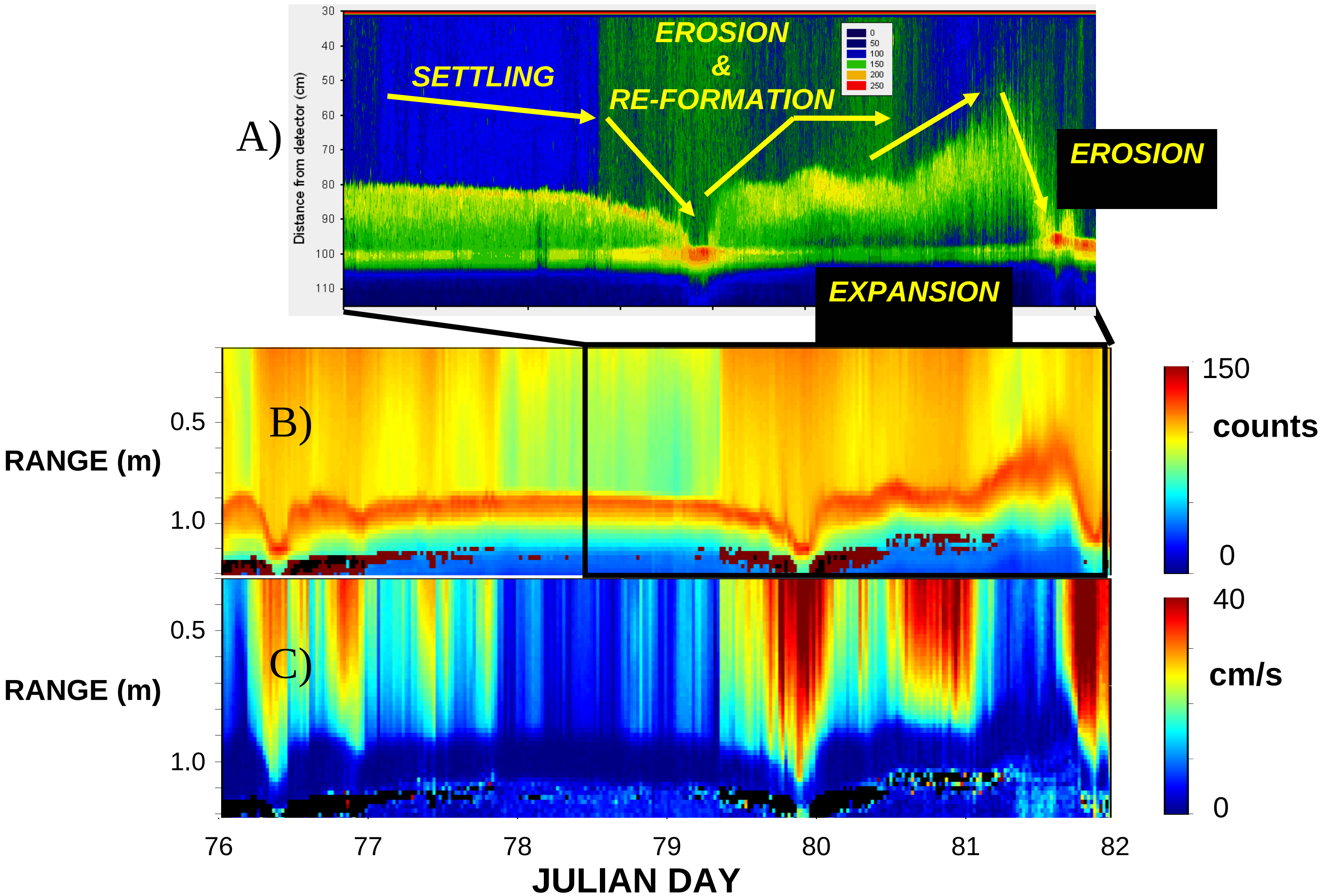


*Figure 4. Observations of complex concentration lutocline (fluid mud density?) behavior over a six day period of relatively low bed stress at the western sites shown in Fig. 1. ADCP current velocity is shown in C, while the lutocline is recorded in ADCP backscatter (B) and from a 700 kHz ABS (A inset of the latter half of the record). The lower frequency ABS records both the lutocline and the underlying bed (at about 100 cm below the detector in A). Note the settling behavior of the lutocline during low stress periods, erosion during strong wind/tidal current stress periods, and expansion (reduced concentration) during moderate stress*